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Estimation of Radiator Performance from Scaled Radiator Testing

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ABSTRACT: The performance of radiators is very important in the case of automobile application. The performance mostly depends on the fin characteristics of the radiators. The size and heat duty of the radiators are very high in some cases particularly in the armoured fighting application. Due to the various constraint particularly limitation in the experimental set up, it is not possible to carry out the experiment with the actual size radiators. Hence, experiments need to be carried out with scaled down size radiators. The results need to be extrapolated for actual size radiators. This paper deals with this aspect.

I. INTRODUCTION

Radiators are used to dissipate the heat load of an engine. It helps to maintain the temperature of engine components within a permissible limit. Both the overcooling and undercooling are detrimental to engine performance. Hence, the performance of a radiator is very critical to ensure engine performance.

The performance of a radiator depends on a large extent on its fin type (coolant and air side). It is not possible to carry out experiments with actual size radiator. Hence, in order to check the fin performance, scaled down size radiator is used due to various constrains (for example power, space) of testing the full scale radiator in a radiator evaluation test facility available with radiator manufacturers. Like all other experimental results [1-2], it is essential to extrapolate the performance data of scaled down radiator to the full scale radiator with the same fin combination. This article describes the procedure for extrapolating the performance of a scaled down radiator to the full scaled radiator, so that performance of actual size radiator can be estimated without carrying out its testing.

II. METHODOLOGY

2. Extrapolation of results

The performance of a radiator of a particular size and fin configuration are predicted by estimating three parameters viz (a) heat transfer rate, (b) coolant side pressure drop and (c) air side pressure drop corresponding to three input parameters viz, (a) inlet potential, (b) coolant mass flow rate and (c) air mass flow rate. To characterise a radiator, three output parameters (heat transfer rate, coolant and air side pressure drops) are evaluated at different combinations of three input parameters (inlet potential, mass flow rates of coolant and air). During extrapolation both input and output parameters need to be extrapolated.

2.1 Extrapolation of air side pressure drop

Air side pressure drop is estimated on a scaled down model for different mass flow rates of air. After extrapolation, pressure drop in the actual radiator will be obtained with respect to extrapolated mass flow rates of air.

During extrapolation of the air mass flow rate, the Reynolds number of actual radiator needs to be considered as same as that for test condition of scaled down radiator, because the friction factor depends completely on Reynolds number only.

As same fin is used for both actual and scaled down radiator, their fin hydraulic diameters are same. Hence, to maintain same air side Reynolds number for both the scaled down and actual size radiator, air velocity in the case of the actual radiator needs to be considered as same as that for test condition of scaled down radiator (Reynolds number depends on air velocity, fin hydraulic diameter and air kinematic viscosity).

The flow area ($A_{f,a}$) of air is known for the both actual ($A_{f,act,a}$) and scaled down ($A_{f,s,a}$) radiator is known.

Hence, the mass flow rate of air for the actual radiator ($m_{act,a}$) corresponding to the test condition of the scaled down radiator ($m_{s,a}$) is

$$m_{act,a} = m_{s,a} \times \frac{A_{f,act,a}}{A_{f,s,a}} \quad (1)$$

As Reynolds number and velocity of the actual radiator are maintained as same as that for test condition of scaled down radiator, the air side pressure drop for $m_{act,a}$ of air flow rate in the actual radiator will increase proportional to the thickness (th) of the radiator.

If $p_{s,a}$ is the pressure drop obtained for m_s flow rate of air in the scaled down radiator, then pressure drop p_{act} in the actual radiator for $m_{act,a}$ air mass flow rate will be obtained as,

$$p_{act,a} = p_{s,a} \times \frac{th_{act,a}}{th_{s,a}} \quad (2)$$

If $p_{s,a,1}$ $p_{s,a,2}$,..... $p_{s,a,n}$ are obtained for scaled down radiator at $m_{s,a,1}$, $m_{s,a,2}$,..... $m_{s,a,n}$ mass flow rates of air,

Pressure $p_{act,a,1}$, $p_{act,a,2}$,..... $p_{act,a,n}$ will be predicted for $m_{act,a,1}$, $m_{act,a,2}$,..... $m_{act,a,n}$ of actual radiator respectively,

Where $m_{act,a}$ and $p_{act,a}$ can be calculated by using Eq. (1) and (2).

2.2 Coolant side pressure drop

Coolant side pressure drop is estimated on a scaled down model for different mass flow rates of coolant. After extrapolation, pressure drop in the actual radiator will be obtained with respect to extrapolated mass flow rates of coolant.

During extrapolation of the coolant mass flow rate, the Reynolds number of actual radiator needs to be considered as same as that for test condition of scaled down radiator, because the friction factor depends completely on Reynolds number only.

As same fin is used for both the actual and scaled down radiator, their fin hydraulic diameters are same. Hence, to maintain same coolant side Reynolds number for both the scaled down and actual size radiator, coolant velocity in the case of the actual radiator needs to be considered as same as that for test condition of scaled down radiator (Reynolds number depends on air velocity, fin hydraulic diameter and coolant kinematic viscosity).

The flow area ($A_{f,c}$) of coolant is known for the both actual ($A_{f,act,c}$) and scaled down ($A_{f,s,c}$) radiator.

Hence, the mass flow rate of coolant for the actual radiator ($m_{act,c}$) corresponding to the test condition of the scaled down radiator ($m_{s,c}$) is

$$m_{act,c} = m_{s,c} \times \frac{A_{f,act,c}}{A_{f,s,c}} \quad (3)$$

As Reynolds number and velocity of the actual radiator are maintained as same as that for test condition of scaled down radiator, the coolant side pressure drop for $m_{act,c}$ of coolant flow rate in the actual radiator will increase proportional to the coolant flow length (l) of the radiator.

If $p_{s,c}$ is the pressure drop obtained for m_s flow rate of coolant in the scaled down radiator, then pressure drop p_{act} in the actual radiator for $m_{act,c}$ coolant, mass flow rate will be obtained as,

$$p_{act,c} = p_{s,c} \times \frac{l_{act,c}}{l_{s,c}} \quad (4)$$

If $p_{s,c,1}$ $p_{s,c,2}$,..... $p_{s,c,n}$ are obtained for scaled down radiator at $m_{s,c,1}$, $m_{s,c,2}$,..... $m_{s,c,n}$ mass flow rates of coolant,

Pressure $p_{act,c,1}$, $p_{act,c,2}$,..... $p_{act,c,n}$ will be predicted for $m_{act,c,1}$, $m_{act,c,2}$,..... $m_{act,c,n}$ of actual radiator respectively,

Where $m_{act,c}$ and $p_{act,c}$ can be calculated by using Eq. (3) and (4).

2.3 Heat transfer rate

During experimental study on scaled down radiator, heat transfer rate is estimated for a specific mass flow rate of coolant ($m_{s,c}$) and air ($m_{s,a}$) and specific inlet potential.

During extrapolation of results for actual size radiator, mass flow rates of air ($m_{act,a}$) and coolant ($m_{act,c}$) can be estimated using Eqs (1) and (3) respectively.

Heat capacity ratio (r) for the actual size radiator can be calculated by considering $m_{act,a}$ and $m_{act,c}$ and specific heat of coolant and air.

In experimental study, Inlet and Outlet temperatures of coolant and air are measured which are expressed as $t_{a,i}$, $t_{c,i}$, $t_{a,o}$ and $t_{c,o}$.

LMTD (Log mean Temperature Difference) for test condition is estimated as,

$$LMTD = \frac{(t_{c,i} - t_{a,o}) - (t_{c,o} - t_{a,i})}{\ln \frac{(t_{c,i} - t_{a,o})}{(t_{c,o} - t_{a,i})}}$$

UA for the scaled down radiator is estimated using Eq (5)

$$Q = U \cdot A \cdot LMTD \quad (5)$$

where Q is the heat transfer rate, U is the overall heat transfer coefficient and A is the heat transfer area for the scaled down radiator.

During estimation of mass flow rates of coolant and air for the actual radiator, the coolant and air side velocity of the actual radiator is to be maintained as same as those of the scaled down radiator.

As both the radiator have same fin in the coolant and air passage, corresponding hydraulic diameter is same for both radiator.

Hence coolant and air side Reynolds number of scaled down radiator is same as those of actual size radiator (due to the same velocity and hydraulic diameter in both cases). So coolant and air side heat transfer coefficient of scaled down radiator is same as those of the actual size radiator. This results in the same overall heat transfer coefficient (U) for both the scaled down radiator and the actual size radiator.

The fin compactness ratio (β) is same for both the scaled down radiator and the actual size radiator, as both of them have same fin. So the ratio of heat transfer area for the scaled down radiator and the actual radiator is the same as the ratio of their volume.

UA of the actual radiator can be calculated by Eq. (6)

$$UA_{act} = UA_{act} \times \frac{v_{act}}{v_s} \quad (7)$$

NTU (Number of Transfer Unit) for actual radiator is calculated by Eq. (8)

$$NTU = \frac{UA_{act}}{(mc_p)_{a,act}} \quad (8)$$

Effectiveness (ϵ) of this radiator can be estimated from Eq. (9)

$$\epsilon = f(\text{NTU}, r) \tag{9}$$

The maximum possible heat transfer of this radiator is calculated by Eq. (10)

$$Q_{max} = (mc_p)_{a,act} x(t_{i,c} - t_{i,a}) \tag{10}$$

Heat transfer rate of the actual radiator with the coolant and mass flow rate of ($m_{act,a}$) and coolant ($m_{act,c}$) respectively and temperature potential same as the condition is estimated by Eq. (11)

$$Q_{act} = \epsilon \times Q_{max} \tag{11}$$

If $Q_{s,1}, Q_{s,2}, \dots, Q_{s,n}$ are obtained for scaled down radiator at $m_{s,c,1}, m_{s,c,2}, \dots, m_{s,c,n}$ mass flow rates of coolant and $m_{s,a,1}, m_{s,a,2}, \dots, m_{s,a,n}$ mass flow rates of air, the heat transfer rate $Q_{act,1}, Q_{act,2}, \dots, Q_{act,n}$ for the actual radiator with $m_{act,c,1}, m_{act,c,2}, \dots, m_{act,c,n}$ mass flow rates of coolant and $m_{act,a,1}, m_{act,a,2}, \dots, m_{act,a,n}$ mass flow rates of air can be estimated by the above described method.

III. EXPERIMENTAL RESULTS

3. Examples of extrapolated results:

Air side pressure drop obtained in the radiator of size 250x300x38 mm and that extrapolated to a radiator of size 341x400x75 mm is shown in Figs 1 and 2 (both the radiators have same combinations of fin).

Heat transfer obtained in the radiator of size 341x400x75 mm and that extrapolated to a radiator of size 341x400x75 mm is shown in Figs 3 and 4 (both the radiators have same combinations of fin).

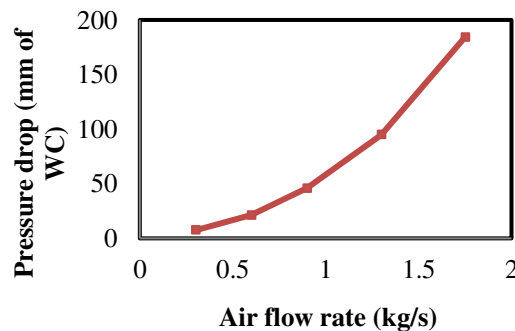


Fig 1: Air side pressure drop at different mass flow rates of air for 250x300x38 mm radiator

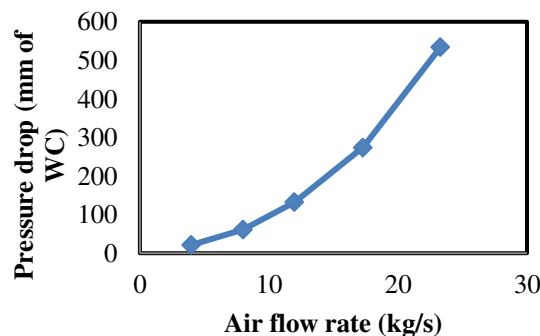


Fig 2: Air side pressure drop at different mass flow rates of air for 1100x860x68 mm radiator

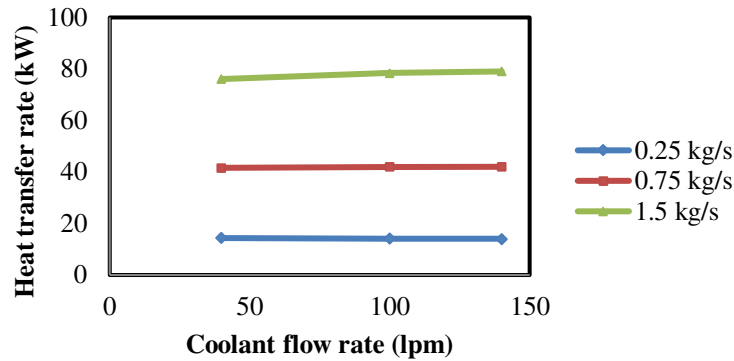


Fig 3: Heat transfer rates at different flow rates of air (kg/s) and coolant (lpm) for 341x400x75 mm radiator at 60°C inlet potential

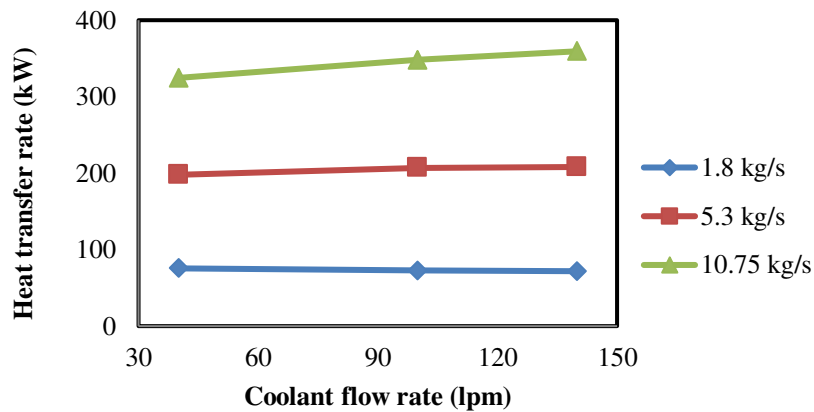


Fig 4: Heat transfer rates at different flow rates of air (kg/s) and coolant (lpm) for 1100x860x68 mm radiator at 60°C inlet potential

IV. CONCLUSION

4. Conclusions:

This paper describes the method for extrapolation of results obtained during testing of scaled down radiator. In addition, the mass flow rates of air and coolant during testing of scaled down radiator also need to be extrapolated for getting the results of actual size radiator. This method is also described in the present paper. Hence, during carrying out the experiments with scaled radiator, mass flow rates of coolant and air need to be selected judiciously so that after extrapolation they correspond to the required mass flow rates of coolant and in the actual size radiator. Scaled radiator can be tested in a small test set up and power requirement is also less for carrying out test with scaled radiator than that with actual size radiator.

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